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High-Level Web Service for 3D Building Information Visualization and Analysis

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ABSTRACT
This paper presents an approach to visualize and analyze 3D building information models within virtual 3D city models. Building information models (BIMs) formalize and represent detailed information related to the lifecycle of buildings, e.g., information about composition, facilities, equipment, usage, maintenance, and workflows such as rescue scenarios. Complementary, virtual 3D city models represent objects and phenomena of urban areas, typically at a lower level of information detail; virtual 3D city models as a general framework and platform for spatial data allow us to seamlessly combine GIS and BIM data. In our approach, BIM data and 3D geodata, both provided by possibly distributed, heterogeneous web services, are efficiently integrated by the underlying real-time 3D geovisualization system. To facilitate insights into complex spatial scenarios, two configurable BIM-specific visualization techniques have been developed, which map BIM data onto 3D building graphics variables respectively geometrically distort 3D building representations. The visualization functionality can itself be accessed as a specialized web 3D perspective view service. We demonstrate our approach by a fire and rescue scenario for a part of a 3D campus model.

Categories and Subject Descriptors
C.0 [Computer Systems Organization]: General – *system architectures.* C.2.4 [Computer-Communication-Network]: Distributed Systems – *distributed applications.* H.3.4 [Information Storage and Retrieval]: Systems and Software – *distributed systems.* H.4.2 [Information Systems Application]: Types of Systems – *decision support.* I.3.3 [Computer Graphics]: Picture/Image Generation – *viewing algorithms.* I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism – *virtual reality.* I.3.8 [Computer Graphics]: Applications.

General Terms
Design, Human Factors, Management, Standardization.

Keywords
Web Services, Building Information Models, Virtual 3D City Models, Geovisualization.

1. INTRODUCTION
One of the key requirements of geoinformation systems and applications represents the integration of heterogeneous, distributed geoinformation from different domains and at different scales. As a fundamental conceptual and technical framework, virtual 3D city models can effectively represent georeferenced objects and phenomena of entire urban areas in a systematic way. Virtual 3D city models are used in a growing number of decision-support and geoinformation systems as a general type of geoinformation user interface.

While a growing number of manifold geoinformation sources become available, detailed information about individual buildings is typically not managed nor represented by GIS data. To enhance and complement virtual 3D city models in this respect, information provided by CAD models and other building-management tools needs to be integrated and helps to bridge the gap between the BIM, CAD, and GIS domains (Figure 1).

In this paper, we describe an approach to visualize and analyze CAD-based 3D building information models (BIM) within 3D virtual city models. This way, detailed georeferenced building information about usage, structure, properties, and associated workflows becomes available embedded into their spatial context. Without such integration, we would not be able to see the spatial context of BIM. Furthermore, the approach represents a general strategy to seamlessly integrate georeferenced data from the domain of CAD with GIS data at the visualization level.

We assume that BIM data as well as 3D geodata are both available from web services such as WFS and WMS. Based on the 3D geodata, our 3D viewer system creates a virtual 3D city model as a specialized kind of geovirtual environment, in which we can embed the BIM data.

We extend the visualization features for building models provided by the 3D viewer by two BIM-specific visualization techniques. One technique is based on mapping BIM data on graphics variables of 3D building models, while the other is based on a geometrically distorted and rearranged view of components of 3D building models. With these techniques, we facilitate understanding and insight into complex BIMs.

The 3D viewer client we developed is based on web services that provide the underlying BIM data and GIS data. In addition, the

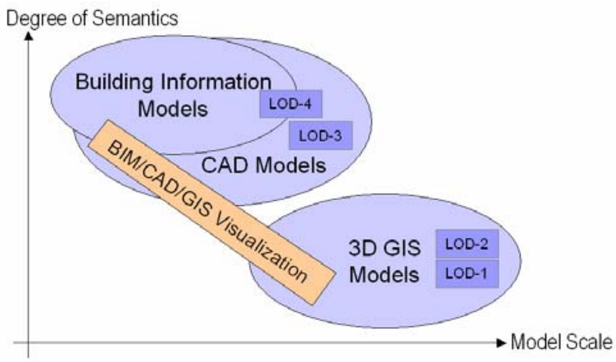

Figure 1: Scales and degree of semantics found in 3D building models with corresponding CityGML level-of-detail categories; the proposed visualization bridges the gap between BIM, CAD, and GIS model use.

3D viewer client can itself operate as a high-level web service providing BIM-specific 3D visualization by a specialized 3D perspective view service.

We illustrate our approach by a virtual 3D campus model using BIM as basis for a fire and rescue scenario. We describe visualization views and styles as well as the supported 3D interaction.

2. BUILDING INFORMATION MODELS

2.1 Elements of BIMs

The main goal for defining BIM standards is to provide a common model for a set of building-related information, which is basis for cross-domain communication and building lifecycle support, and thereby enabling interoperability between different domains, participants, and systems. A BIM defines an ontology for the main building structures such as rooms, stories, slabs, walls, roofs, beams, stairs, doors, windows, etc. Additionally to this semantics, the model can include information about the geometry of each entity (i.e., position and extension), additional attributes, topology information (e.g., connectivity of rooms), or other relationships (e.g., groupings into building parts).

Because BIMs are intended for a variety of application domains, different people, and different purposes, they must provide flexibility for representing building-related features and attributes, which are not known a priori. In addition, workflows such as plans for rescue, emergence, and inspection can be built on BIMs.

2.2 Examples of BIMs

2.2.1 Industry Foundation Classes (IFC)

The Industry Foundation Classes (IFC) are a comprehensive example for a BIM standard, which has been developed by the International Alliance for Interoperability (IAI, 2007). IFC has been evolved to an industrial standard, which is widely used by many vendors in the AEC and F&M field and has been deployed by different authorities for their own BIM standards, e.g., the GSA BIM Standard (GSA, 2007) and the National BIM Standard (NBIMS, 2007).

IFC is a powerful standard for an in-detail architectural specification of building models including their internal infrastructure and development history. In addition, IFC provides IfcPropertySets for the definition of domain-specific data. They contain properties, which are interpreted according to their names. The IAI has supported several projects for extending IFC for special domains such as HVAC, electrical installations, or structural analysis (IAI, 2007).

2.2.2 CityGML

CityGML denotes a general information model for representing geovirtual 3D environments such as virtual 3D city models; it introduces classes and relations for topographic objects of urban environments and regional models including their semantics, geometry, topology, and appearance (Kolbe et al., 2005). CityGML supports also generalization hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. CityGML uses a transparent data model based on XML for storage and exchange (Gröger et al., 2006) and is implemented as an application schema for the Geography Markup Language 3 (GML3).

In contrast to IFC, CityGML concentrates on regional 3D information models that in most cases consist of hundreds of components, which not only represent buildings but also their environment. The general object types supported by CityGML include:

- Terrain models including grid-based and TIN-based representations;
- Building models at four levels of quality, which are block models (LOD-1), geometry models (LOD-2), architectural models (LOD-3), and interior models (LOD-4);
- Site models such as for bridges, tunnels, and monuments;
- Vegetation models to represent plants and biotopes;
- Water models to represent water bodies, rivers, and lakes;
- Traffic and transportation network models;
- City furniture models such as streetlights, park benches;
- Thematic models (e.g., landuse);
- Hierarchical aggregations of generic city objects.

With respect to building information, CityGML provides a limited support, typically restricted to the graphical appearance of related 3D objects. In LOD-4 building models we can specify building parts, rooms, different types of walls and slabs, roofs, openings (e.g., windows and doors), so-called building furniture, or arbitrary building installations (for representing balconies, stairs, chimneys, etc.). Meta-information that can be attached to CityGML objects include address, function, usage of buildings and rooms. Figure 2 shows BIM-related parts of the CityGML schema.

CityGML can be extended for specialized domains and purposes by generic attributes and classes as well as by application domain extensions. In this way we can include building information into a CityGML-based virtual 3D city model.

2.3 BIM for a Fire Rescue Scenario

Fire and rescue is one domain where the availability of building information is of high interest for saving people and assets. The following geo-referenced building information can be considered relevant for such fire and rescue scenarios:

- Fire extinguishers;
- Sensors such as smoke detectors, temperature sensors, or motion detectors for estimating the source of fire and the overall condition;
- Sprinklers, hydrants, hose reels, rising mains;
- Statics and material of building structures, e.g. windows;
- Cables, ducts, and funnels spreading heat, fire, and smoke;
- Information about locking of windows and doors (e.g., lattices) and key owners;
- Storage locations of dangerous substances (e.g., gas, oil, cleaning supplies, and chemicals);
- Expected overall number of people, number of people who need assistance (e.g., young and older ones);
- Navigation hints (e.g., room numbers) for supporting the orientation of helpers;
- Tracking information of people and objects.

Fire prevention and fire fighting is regarded by different BIM standards and IFC. So IFC 2x3 includes the "plumbing fire protection domain" and provides a fire compartment as zone of spaces, special fire/smoke dampers, and several relevant property sets, regarding, e.g., fire hydrants, sprinklers, hose reels, and fire rating properties describing the fire resistance of used materials.

Enriching this building information with complementary geospatial information of the surrounding area of the building such as terrain, streets, surrounding buildings and other infrastructure elements, vegetation, water bodies, etc. can further support the process of evaluating the site of fire and aid in making decisions.

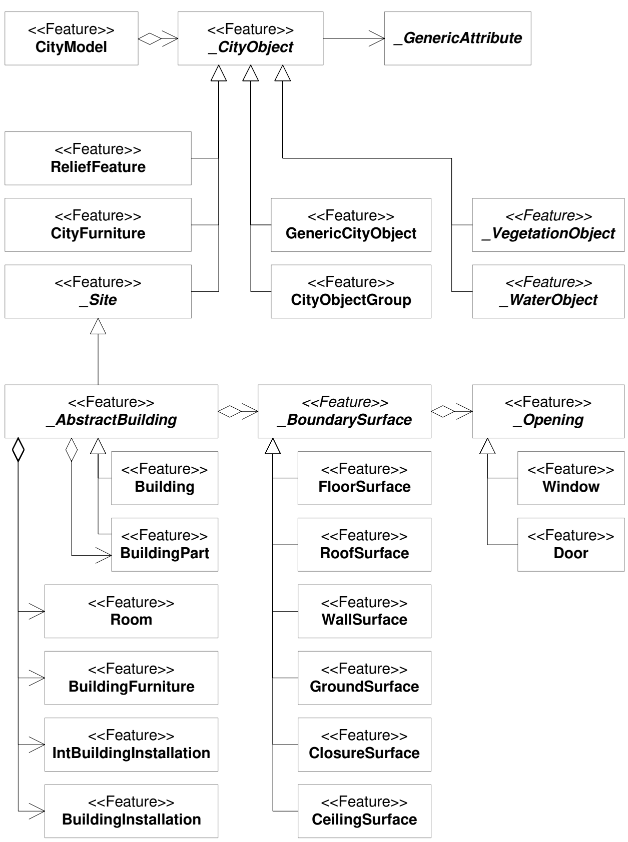

Figure 2. Part of the CityGML schema with BIM-relevant entities and attributes. (From Gröger et al., 2006)

2.4 Mapping BIM to City Model Elements

For the visualization of a BIM within its geospatial context on the bases of a virtual 3D city model, both models have to be integrated. That is, a common representation must be used for bridging the different underlying concepts. One could design a super-model but due to the extreme diversity of vendor-specific formats and domain-specific variants this would hardly be a pragmatic solution. Instead, we apply the virtual 3D city model and its graphics representation for this purpose and extend them in a BIM-specific manner. This kind of "integration at the visualization level" has to map semantic, geometric, and thematic attributes, as well as relationships between entities.

In our approach, we map BIM data to CityGML model data, especially onto the building model, which is a primary thematic concept of CityGML. Since LOD-4 CityGML building models can describe internal building structures, we use them as starting point for mapping BIM to CityGML. For the mapping, we consider the following CityGML model elements as relevant:

- Building: a building entity with a specified identity;
- Building part: component that details buildings (e.g., stories and roofs);
- Building attributes: represent name-value pairs;
- Boundary surface: represents the shell of building and rooms, e.g., roofs, exterior and interior walls, ground surfaces, floors and ceilings;
- Outer building installation: component that belong to the outside of a building, e.g., chimneys, balconies;
- Opening: represents windows and doors in walls;
- Building interior: include rooms, building furniture, internal building installations (e.g., stairs or pipes);
- City object grouping: special city model feature, e.g., for defining stories.

Furthermore, we focus in IFC as main source of BIM, which is supported by numerous vendors in that field. Both models, IFC and CityGML, include the concept of complex buildings formed by aggregating building parts. CityGML defines detailed building elements such as slabs, walls, windows, and doors, onto which IFC data can be mapped directly (Benner et al., 2005). Figure 3 shows an IFC-CityGML example. Nevertheless, not all IFC elements have a canonical representation in CityGML, for example, as in the case of staircases and balconies. While IFC supports various types of shape representation, CityGML only provides a boundary representation. Additionally, a subset of IFC building information details cannot be directly mapped (e.g., curved geometries, physical quantities, layered materials).

To integrate BIM data into a virtual 3D city model, those model entities must be identified that describe aspects of the same real-world entity. This could be done by a common reference (e.g., by building or room identifiers) or by analytical identification (e.g., by comparing their geometric extents). Such combination at the semantics level is essential to enable a precise analysis. If there is no such combination, integration can be achieved at the visualization level on the bases of the geospatial reference. In the case of only a single BIM source (i.e., no additional other

Figure 3. Explosion view of a LOD-4 CityGML building model derived from an IFC model; colors are defined by object type.

building model available) no integration is necessary; the BIM elements can be simply transformed into the corresponding city model elements.

3. VISUALIZATION OF BIM BY VIRTUAL 3D CITY MODELS

Geovisualization is an effective and efficient means for the transfer of geospatial knowledge. Together with appropriate interaction techniques such as navigation or editing, it allows the human user to easily perceive, evaluate, and analyze geoinformation and information with spatial reference. Geovisualization comprises the mapping of geoinformation onto a computer graphics model and the synthesis of images.

Virtual 3D city models represent an important type of geovirtual environment and means for geovisualization. For the visualization of building information we identify two challenging tasks:

- The visualization of internals of composite structures (e.g., enabling an inside-view of a building).
- The visualization of intangible information (e.g., the usage of a room, groupings such as stories)

Both are regarded by the building visualization techniques that are described in this chapter. We present two techniques for the automated ad-hoc visualization of BIM and GIS information. This high-level functionality can be provided in a service-based manner and so can be included into ad-hoc rescue-processes for enabling, e.g., high-quality visualization.

The implementation of our combined GIS and BIM visualization is based on the LandXplorer technology, system and framework for 3D geodata management and real-time 3D geodata visualization (3D Geo, 2007). LandXplorer supports users to create, edit, manage, explore, and analyze complex geovirtual 3D environments, including 3D city models and 3D landscape models.

3.1 Mapping BIM to Visual Variables

Visual variables denote graphical aspects in which visualized entities can be varied for showing differences or relationships. Carpendale (2001) discusses general visual variables, in particular those introduced by cartography; they include position, shape, size, color value and hue, orientation, texture, and motion. On this basis, different visual variables for virtual 3D city models can be identified:

- Shape of city objects (e.g., buildings, trees, outer building installations, facade elements, doors, windows, building interiors);
- Position and orientation of city objects (e.g., doors, windows, rooms);
- Size of city objects (e.g., building height);
- Material, color, and texture of boundary surfaces (e.g., facades, interior walls, roofs) or other city objects;
- Special visualization aspects such as illumination, shading, shadows, edge styles, etc. of boundary surfaces or other city objects.

BIM data generally shows multivariate characteristics. Due to this, each of the properties of a BIM element, e.g., semantics, geometric, and thematic data, can potentially influence the corresponding properties of the city object element it is mapped to. For BIM attributes the different data scales have to be considered: categorical, nominal, ordinal, interval, and rational.

3.2 Mapping BIM to Geometry

For each BIM data to be mapped onto the city model there must be an existing or derived geometry whose appearance can be adjusted according to the type and value of the building information.

If the original building information is of type geometry, this geometry is reused for the city model object. If no such inherent

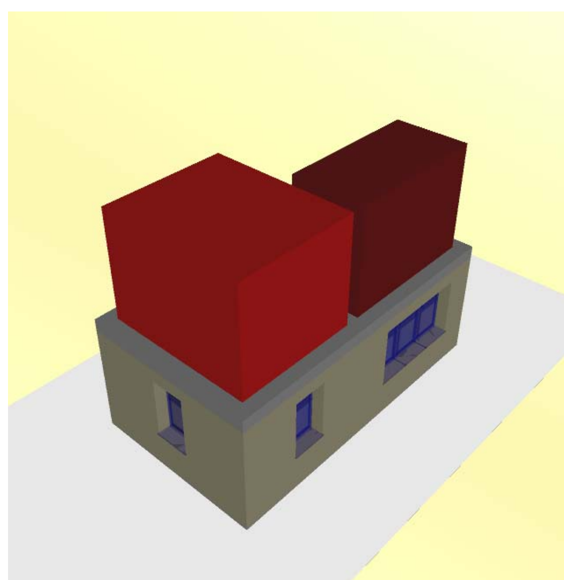

Figure 4. View showing the relative temperature on the second floor.

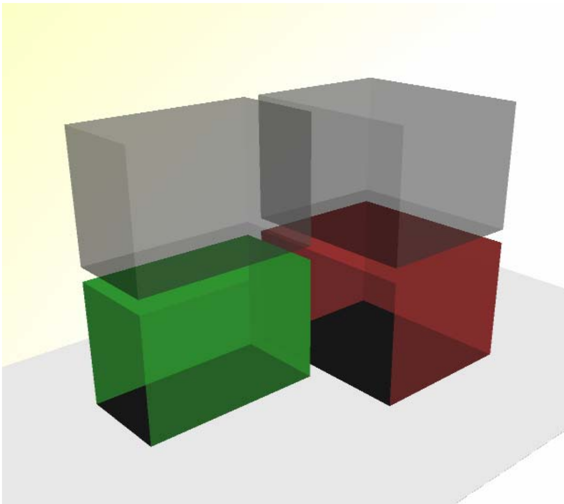

Figure 5. View showing the rooms with hazardous materials.

geometry exists, either another BIM object can be used for representing the building information, or a corresponding geometry has to be generated. For example, derived geometry is required for visualizing relationships such as room's connectivity, escape routes (topology) or stories (grouping of rooms). The geometry can be composed from surfaces, e.g., for extracting the story geometry from all associated walls, windows, etc.

Non-geometric building information can be mapped to attributes of geometry. For example, the energy consumption of buildings could be mapped to the height of the building's block model. Alternatively, non-geometric building information can be represented by annotations of the 3D scene, for example, to visualize the presence of extinguishers, HVAC installations, or first-aid kits. 3D annotations can be visualized by texts, symbols, or 3D objects (e.g. an extinguisher model) and are integrated into the 3D scene or positioned within the view plane as described by Maass and Döllner (2006).

3.3 Emphasized BIM Visualization

One approach for visualizing BIM information hides and emphasizes building structures: Important objects are highlighted and less important objects are reduced in perceptibility or even removed from the visualization. Apart from removal case, this technique leaves geometry unaltered, which enables to perceive and judge the real-world spatial configuration and relationships.

- A *BIM-view* configuration describes the objects that are included or excluded from the visualization and which BIM-style to apply.
- A *BIM-style* controls the visual variables and defines the appearance of city model objects and building objects.

For the visualization of values, a BIM style offers the possibility to define one of the object attributes whose values modify the original object color. Furthermore, a base color hue (whose value is modified) and a normal range for the attribute's values are defined.

According to the rendering, we are using only color, transparency, and outlines for this visualization technique. Another issue is the calculation of a camera position that is appropriate for showing all the selected entities of interest.

Figure 4 shows a 3D campus building. Only its second floor is inspected in detail. The view contains all elements of the first floor in normal style. For the second floor only room objects are included. For the story separation CityObjectGroups have been evaluated. The rooms on second floor are colored according to their temperature value from light red to dark red. In the sense of the fire scenario this can indicate the fire source.

Figure 5 shows another view for identifying any rooms in the building that include any hazardous materials, e.g., oil, gas, or chemicals. Therefore, only rooms of the building are displayed in transparent mode. Only those rooms are colored which contain such materials.

3.4 Deforming Building Structures for BIM Visualization

As another approach to visualizing BIM we distort the geometry of building elements on the basis of their semantics. In detail GityGMLGroupings are evaluated for identifying the stories of a building and all story elements. Those are used for exploding the building model vertically and for popping open the building model vertically, respectively.

For explosion views, a geometrically translation is applied to the building stories and roof. Thereby insight into every story is enabled and indoors elements such as furniture can be perceived without modifying the building objects' appearance, e.g., by using transparency. Such visualization is essential when dynamic data such as tracking data of firefighters shall be integrated with this building model and all their positions shall be visible at the same time.

A second deforming technique just tilts up the building structures above a defined storey, see Figure 6. On the one side this tilting provides less information than the explosion view, on the other side it needs less image space and still contains more information

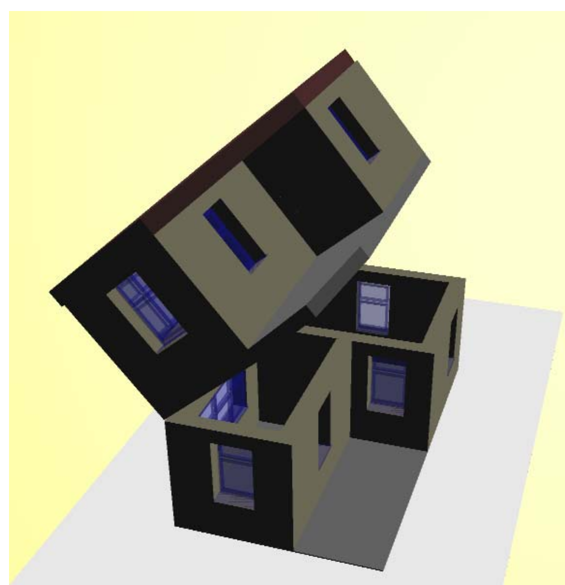

Figure 6. Tilting up of the building for gaining insight.

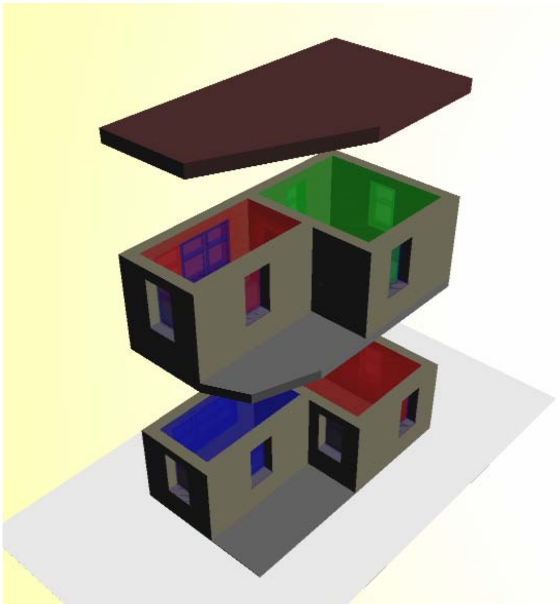

Figure 7. Explosion view for gaining insight; room usage is color coded.

than just removing the upper building parts from the visualization.

As shown in Figure 7 this deforming visualization technique can be combined with the mapping technique described above. The view includes all building information; only for the second floor the room usage is color-coded.

3.5 Room Report as a Concept for BIM Analysis

Building information analysis includes a kind of building decomposition and organizing, inspecting, and evaluating the composites considering the relationships between them. As a basis for the systematical investigation of building information, a common understanding of the underlying classification and its entities is necessary. Complementing this BIM investigation, with the investigation of GIS data, leads to a holistic approach for (semantical and geospatial) building information analysis.

As a concept for such building information analysis we provide a tool with room report functionality. The tool allows the user to include or exclude different data sources such as GIS and BIM information from the analysis process, to select a room report (i.e., the features and attributes the user is interested in), and to request a visual representation of the report.

The visualization of specific building information is an essential part of this room report tool, which therefor uses the web service described in chapter 4.

4. WEB PERSPECTIVE VIEW SERVICE for BIM (BIM-WPVS)

4.1 High-Level Geoinformation Services

The OGC web services such as Web Feature Service (WFS), Web Coverage Service (WCS), and Web Map Service (WMS) provide means to communicate geodata and can be considered generic, low-level geoinformation services. However, current geodata infrastructures need to evolve towards integrated systems for the provision of customized information and services (Morales and Radwan, 2004). Yet in a number of application-specific web services, higher-level geoinformation services are implemented, e.g., for interoperable 3D emergency routing (Neis et al., 2007), for indoor navigation (Mäs, 2006), and orchestration of web services for disaster management (Weiser and Zipf, 2007).

High-level geoinformation services are generally characterized by the following capabilities and functionalities:

- **Enhancing geoinformation:** Include services that enhance geodata by adding, manipulating, correcting, or transforming geodata, e.g., a specialized mass coordinate transformation.
- **Provision of business functionality:** Include services that implement domain-specific knowledge and provide functionality such as adding business data to geodata; these services are essential for implementing business processes.
- **Integration of complex geoinformation:** The services typically integrate heterogeneous, distributed geodata at the modeling level or at the visualization level (Döllner and Hagedorn, 2007).
- **Provision of high-quality geovisualizations:** Geovisualization is essential for geoinformation-based systems and applications. "High quality" refers to enhanced, stylized, or physical-based, photorealistic depictions of 3D geovirtual environments as well as to user-oriented and task-oriented depictions of geoinformation.
- **Support of user interaction:** Services that provide user interaction can be deployed at the application level (Voisard and Schweppe, 1998). They provide, for example, domain-specific exploration and analysis functionality, accessible through a user interface.
- **Support of context-awareness:** Context-awareness refers to identifying and providing information about the tasks the user fulfills and the devices that the users deploys.

4.2 The BIM Visualization Web Service

The geoinformation service for integrating and visualizing BIM and GIS data represents a kind of high-level web service. It is designed as a specialized Web Perspective View Service (WPVS) for building information (BIM-WPVS) and addresses the following requirements:

- Integration of 2D/3D GIS data and BIM data from diverse sources at the visualization level;
- Provision of high-quality visualizations;
- Configurable 3D views and rendering styles;
- Automated calculation of the camera positions.

In general, we could implement the BIM-related high-level geoinformation service on top of the following OGC web services:

- **Data-oriented:** A Web Feature Service (WFS) would deliver and modify feature objects and their attributes;
- **Scenegraph-oriented:** A Web 3D Service (W3DS) would deliver a scene graph, i.e., a specification of a virtual 3D world including 3D objects, their attributes und hierarchical

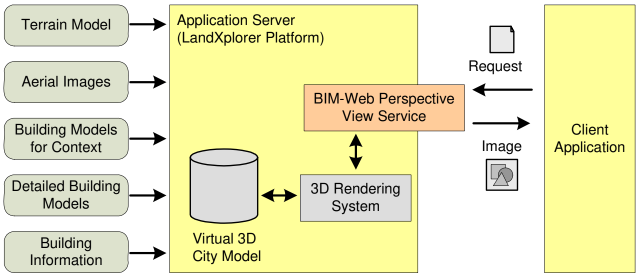

Figure 8. System architecture of the BIM-WPVS.

structure; this data is processed by 3D rendering engines for visualization.

- **Visualization-oriented:** A Web Perspective View Service (WPVS) would provide perspective views of a static 3D scene as image, i.e., a rendering of a geovirtual 3D environment.

We decided to implement the BIM in a visualization-oriented way. Using a WPVS has the key advantage that there is no need for consumer-side 3D rendering because image synthesis is performed at the server side; the server can be equipped with appropriate 3D computer graphics hardware. In particular, we can deploy high-quality 3D rendering without having to consider the diverse client 3D rendering capabilities since BIM visualization results need only to be transferred to and displayed by light-weight client applications (Singh, 2001). This separation of geovisualization concerns allows us to implement specialized 3D visualization techniques such as for natural phenomena (e.g., including water or sky), to apply processing-intensive techniques (e.g., non-photorealistic rendering, vegetation rendering, or ambient occlusion for simulating global illumination in geovirtual environments).

As a disadvantage, WPVS (as well as W3DS) do not transfer any further semantics to the client than the information contained in the synthesized image (or scene graph, respectively). Semantical information is currently only provided by data services, such as the OGC WFS, which, e.g., could deliver a semantical model of a geospatial scene in the CityGML format. This approach would require additional knowledge about the format and processing of CityGML at the service consumer side.

Compared to the OGC WPVS, our BIM-WPVS is extended as follows:

- BIM-WPVS includes integration capabilities for different geoinformation, i.e., terrain data, vegetation, several building data, and additional building information.
- BIM-WPVS provides different views that are configurable with respect to visualized data and visualization style.

The perspective view provided by the BIM-WPVS can be integrated into different processes for giving users insight into the geoinformation in an effective way. The application of the BIM-WPVS can be further enhanced by the combination with other services which could enable the access to further complex geoinformation (e.g., to ad-hoc sensor network data), provide functionality for further improving the visual representation of the virtual 3D environment (e.g., by adding annotations to the view), or supply interaction capabilities (e.g., for navigation and editing).

Security is another important issue that can be addressed with service composition. In the context of a BIM-WPVS this includes user authentication and authorizing the access to the underlying data which has to be appointed with user restrictions, accordingly.

4.3 Service Architecture

Figure 8 illustrates the system architecture of the BIM-WPVS. Various sources and formats of geoinformation are accessed, integrated and composed by the central LandXplorer-based server component. It is capable of integrating terrain data, aerial images, LOD-4 building models, additional detailed building information, and further context buildings for the geospatial surrounding on the basis of a virtual 3D city model.

In our case the different geoinformation is accessed from a central database, but it might be distributed and could be accessed by using WFS and WMS web service adaptors that we have added to the LandXplorer CityGML viewer as a contribution to the CAD/GIS/BIM thread within OGC's web services initiative, phase 4 (OGC, 2007). In contrast to that work, the BIM-WPVS deploys a fat-server/thin-client approach.

4.4 Service Interface

Similar to the OGC WPVS, the BIM-WPVS provides two operations, GetCapabilities, which provides information about the service and its capabilities, and GetView, which provides the synthesized image.

- **GetCapabilities:** Describes the geoinformation layers that are available through the service and can be selected by the service consumer for visualization. Building information is modeled as one layer of the BIM-WPVS. The GetCapabilities response further describes different general analysis views, which can be chosen for the server-side image rendering process. These views define the in-scope building information and how they are visualized.
- **GetView:** It provides the capabilities of the BIM-WPVS to the service consumer, i.e., the rendering of an image that emphasizes specific building information. For its configuration, the service provides several parameters which a) define the geoinformation layers to include, b) define the position of the virtual camera or leave this to the server for

Figure 9. Tilt up view of a large campus building within its geospatial context.

automated calculation, c) define the requested image size, d) define the general analysis view to apply, or e) define a task- and domain-specific view with explicitly setting the relevant entities and the visualization style.

Figure 9 shows the result for a GetView request which integrates detailed building information for a large campus building within its geospatial context (i.e., terrain data and aerial image) and uses the tilt up view to allow the service consumer to gain insight into the building structure and properties.

5. CONCLUSIONS

We have outlined design and implementation of a high-level geoinformation service that helps to close the gap between spatial information at the building level and spatial information at the city model level. We have explained how to map BIM data to components of virtual 3D city models, and exemplified the approach by two BIM-specific visualization techniques. We demonstrated the applicability of the approach by our implementation of a BIM-WPVS, which successfully utilizes virtual 3D city models for seamlessly integrating and visualizing GIS and BIM data; rendering styles can be configured by the service operation parameters and different views for analysis purposes can be obtained.

As a general insight, we consider the BIM-WPVS as an example of a high-level geoinformation service that synthesizes complex data and applies advanced 3D visualization techniques while offering a high degree of interoperability due to the server-side 3D rendering.

In our future work, we will develop advanced BIM visualization techniques that focus on providing insight into complex spatial assemblies using non-photorealistic, illustrative 3D rendering techniques. In addition, we will focus on combining the BIM-WPVS with other geoinformation and visualization services.

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